

## APPENDIX F FIGURES

Figure F- 1: Central Arkansas Case Study Regional Area .....	1
Figure F- 2: East Arkoma Basin Structural Cross-Section (with permission) .....	2
Figure F- 3: Cross-Section of Active Fault Plane (Figure 3 of Horton, 2012) .....	3
Figure F- 4: Stratigraphic and Hydrologic Column of the Arkoma Basin (Ausbrooks and Horton, 2013).....	4
Figure F- 5: Central Arkansas Historic Area Seismicity in Focus Area through 9/30/2013.....	5
Figure F- 6: Composite Focus Area Seismicity Map .....	6
Figure F- 7: Seismometer Deployment and Active Fault Trace (Horton, 2012) .....	7
Figure F- 8: Central Arkansas Composite Focus Area Seismicity.....	8
Figure F- 9: Moore Estate Operational Data Plot .....	8
Figure F- 10: SRE Operating Data Plot .....	9
Figure F- 11: Trammel Operating Data Plot.....	9
Figure F- 12: Underwood Operating Data Plot .....	10
Figure F- 13: Edgmon Operating Data Plot.....	10
Figure F- 14: Moore Estate Operating Pressure Gradient Plot .....	11
Figure F- 15: SRE Operating Pressure Gradient Plot .....	11
Figure F- 16: Trammel Operating Pressure Gradient Plot.....	12
Figure F- 17: Underwood Operating Pressure Gradient Plot .....	12
Figure F- 18: Edgmon Operating Pressure Gradient Plot.....	13
Figure F- 19: Moore Estate Tandem Plot of Cumulative Earthquake Events and Hall Integral with Derivative .....	13
Figure F- 20: Moore Estate Tandem Plot of Cumulative Earthquakes since 2010 and Hall Integral .....	14
Figure F- 21: Moore Estate Zoomed Tandem Plot .....	14
Figure F- 22: SRE Tandem Plot of Cumulative Earthquakes and Hall Integral with Derivative ....	15
Figure F- 23: SRE Zoomed Tandem Plot to November 21, 2010 .....	15
Figure F- 24: Trammel Tandem Plot of Cumulative Earthquake Events and Hall Integral with Derivative .....	16
Figure F- 25: Trammel Tandem Plot of Cumulative Earthquakes and Hall Integral .....	16
Figure F- 26: Edgmon TANDEM PLOT OF CUMULATIVE EARTHQUAKES AND Hall Integral WITH Derivative .....	17
Figure F- 27: Edgmon Tandem Plot of CUMulative Earthquake Events and Hall Integral.....	17
Figure F- 28: Edgmon Zoomed Tandem plot of Early Data to December 19, 2010 .....	18
Figure F- 29: Edgmon Step Rate Test .....	18
Figure F- 30: SRE Log-log plot of Pressure Falloff During Final Shut-in of Well .....	19
Figure F- 31: Trammel Log-log Plot of Pressure Falloff During Final Shut-in of Well .....	19
Figure F- 32: Edgmon Log-log Plot of Pressure Falloff During Final Shut-in of WELL.....	20

FIGURE F-1: CENTRAL ARKANSAS CASE STUDY REGIONAL AREA

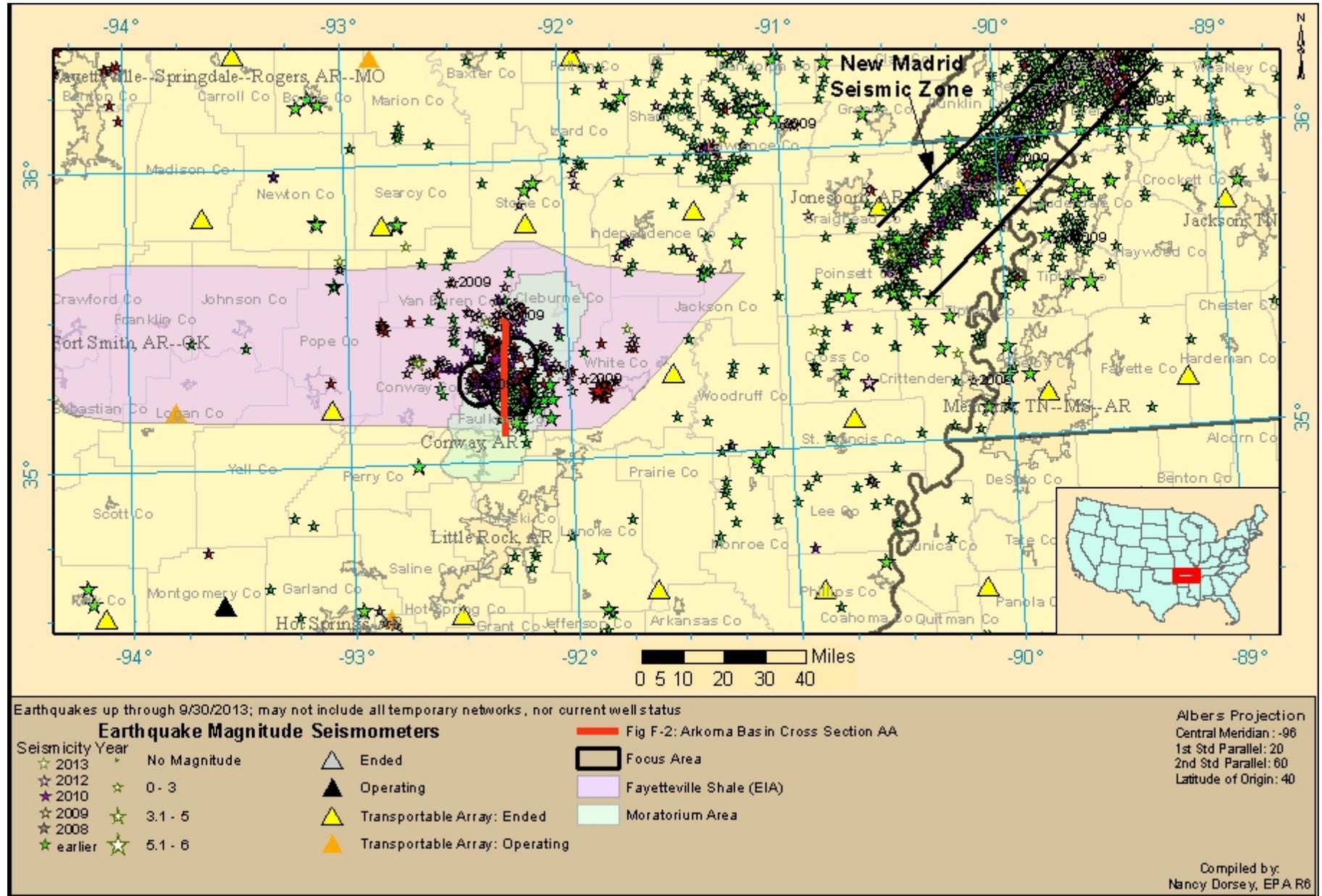


FIGURE F- 2: EAST ARKOMA BASIN STRUCTURAL CROSS-SECTION (WITH PERMISSION)

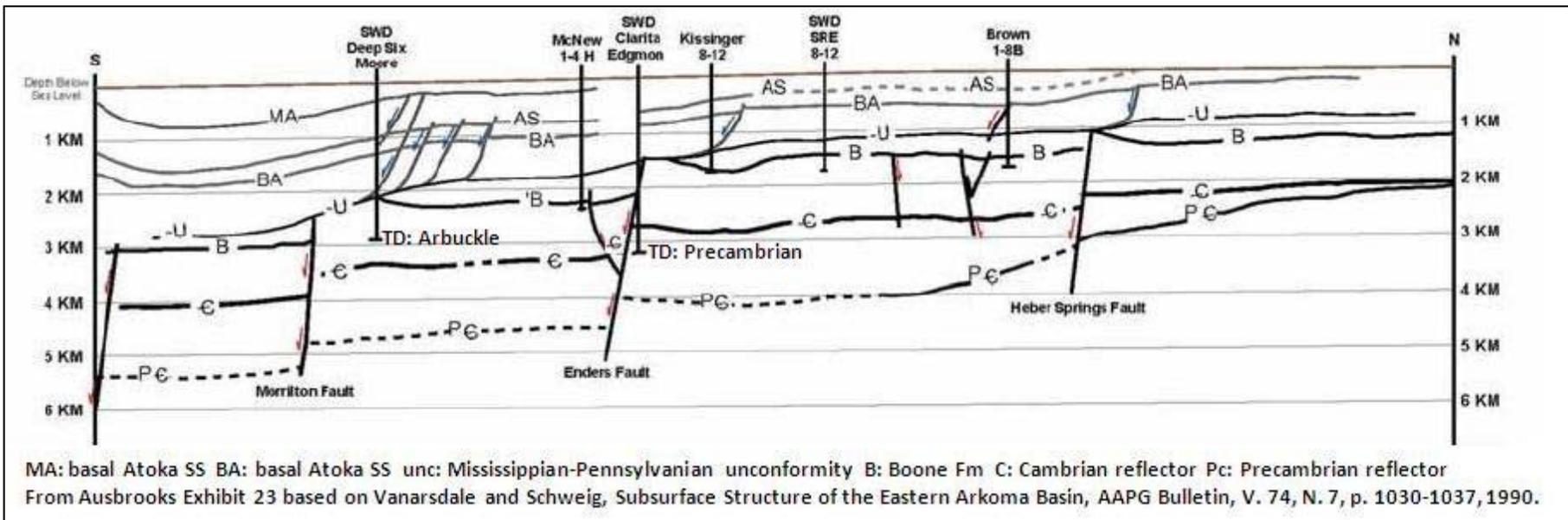
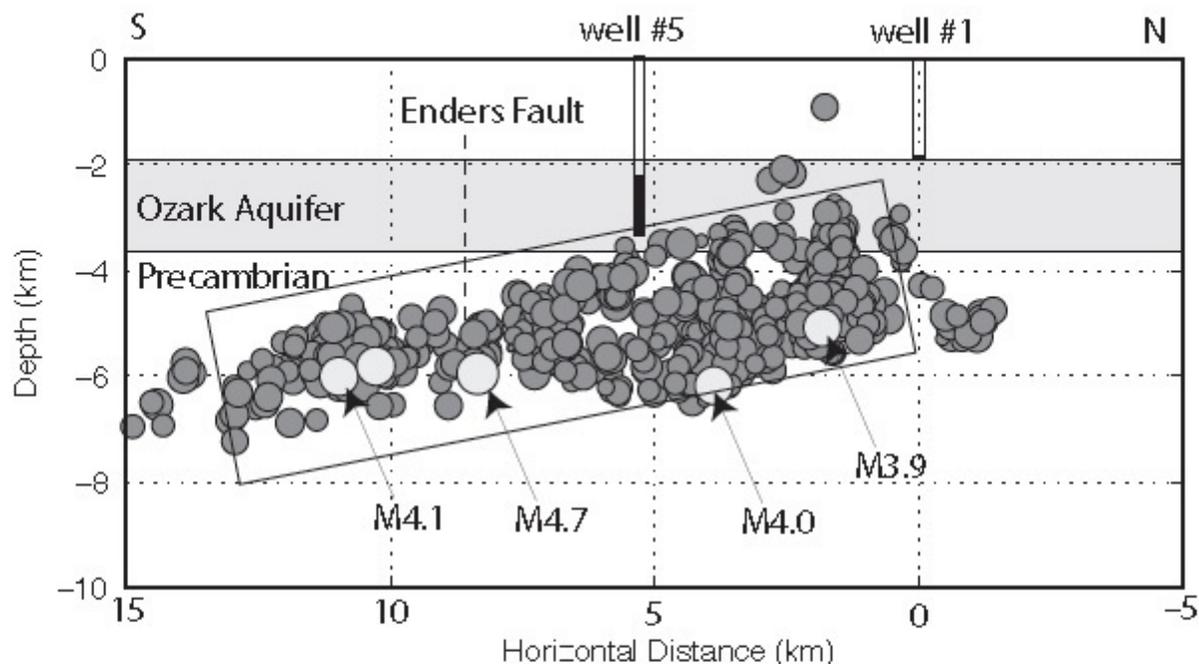


FIGURE F- 3: CROSS-SECTION OF ACTIVE FAULT PLANE (FIGURE 3 OF HORTON, 2012)



▲ **Figure 3.** Cross-section showing earthquake hypocenters looking N60W. Rectangle is 13 × 3.2 km and dips 11°. Shaded rectangle indicates the approximate vertical extent of the Ozark aquifer with the bottom boundary depth determined in well #5 and the top boundary depth determined in well #1. Solid black portion of each well indicates the interval where fluid is injected. The dashed line indicating the Enders fault is approximate. The larger earthquakes (light gray circles) rupture the deeper portions of the fault.

Horton, S. P., 2012, Disposal of Hydrofracking-waste fluid by injection into subsurface aquifers triggers earthquake swarm in Central Arkansas with potential for damaging earthquakes: *Seismological Research Letters*, v. 83, p. 250-260, doi: 10.1785/gssrl.83.2.250.

Wells: 1 = SRE 8-12 1-17; 5 = Edgmon 1

FIGURE F- 4: STRATIGRAPHIC AND HYDROLOGIC COLUMN OF THE ARKOMA BASIN (AUSBROOKS AND HORTON, 2013)

STRATIGRAPHIC SECTION, GEOHYDROLOGIC UNITS AND REGIONAL TECTONIC EVENTS EASTERN ARKOMA BASIN											
Modified from Caplan, 1954											
SYSTEM	SUBSYSTEM	GROUP	FORMATIONS / Units	CROSS-SECTION REFLECTORS	GEOHYDROLOGIC UNITS	TECTONICS/ GEOLOGIC HISTORY					
PENNSYLVANIAN	DES MOINESIAN	ATOKAN	MISSING	299 Ma	WESTERN INTERIOR PLAINS CONFINING UNIT	Continued elevation of the Ozark Platform... Late Pennsylvanian Ouachita Orogeny thrusting and formation of the Ross Creek thrust fault (Arbenz, 1984; Denison, 1989)  Compression from the south causes over-thrusting and E to W trending belt of folds in the basin (Sutherland, 1988)  Development of listric down-to-the-south normal (growth) faults within the Morrowan and Atoka strata with the faults terminating in the Mississippi-Pennsylvanian unconformity surface on the north side of the large E to W normal faults (Van Arsdale and Schweig, 1990)  Accelerated sedimentation rates  Deposition of the Pennsylvanian Morrowan and Atokan strata... Clastics dominate the depositional environment					
			HARTSHORNE	MA							
			Carpenter 'A' Upper Alma Middle Alma Lower Alma Carpenter 'B'								
			MIDDLE ATOKA	GLASSEY			Tackett (Morris) Aeci Bynum Frieburg Casey	AS			
									LOWER ATOKA	BA	
			MORROWAN	ATOKA			Sells (Dunn 'A') Ralph BARTON Dunn 'B' Dunn 'C' PAUL Barton Cecil Spiro Patterson	U			
							BLOYD SHALE				
			MISSISSIPPIAN	CHES. TERRAIN			HUNTON	HALE FORMATION	318 Ma	OZARK AQUIFER	Major subsidence of the Arkoma Basin forming large E to W turning NE down-to-the-south normal faulting (Frezon and Glick, 1959) and formation of footwall anticlines in Late Mississippian due to loading south of the Arkoma Basin (Houseknecht, 1986)  Regional downwarping of Reelfoot Rift caused by cooling and subsidence (Caplan, 1954)  Evolution of southern margin of North American into a passive margin (Caplan, 1954)... Deposition of Cambrian to Late Mississippian Carbonates
								PITKIN LIMESTONE	B		
								FAYETTEVILLE SHALE			
BATESVILLE SS	359 Ma										
MOOREFIELD FM											
BOONE FORMATION	C										
CHATTANOOGA SHALE											
PENTERS CHERT	444 Ma										
LAFFERTY LS											
ST. CLAIR LS	488 Ma										
BRASSFIELD LS											
CASON SHALE	C										
FERNVALE LS											
KIMMSWICK LS	542 Ma										
PLATTIN LS											
JOACHIM DOLO	PC										
ST. PETER SANDSTONE											
EVERTON FORMATION	ST. FRANCOIS CONFINING UNIT (MISSING IN STUDY AREA)										
POWELL DOLOMITE											
COTTER DOLOMITE	ST. FRANCOIS AQUIFER										
JEFFERSON CITY DOLO											
ROUBIDOUX FM	BASEMENT CONFINING UNIT										
GASCONADE DOLO											
EMINENCE DOLOMITE	BASEMENT GRANITE AND RHYOLITE										
POTOSI											
DERBY-DOERUN-DAVIS	BASEMENT GRANITE AND RHYOLITE										
BONNETERRE DOLO											
REGAN SANDSTONE	BASEMENT GRANITE AND RHYOLITE										
LAMOTTE SANDSTONE											
PC	BASEMENT GRANITE AND RHYOLITE										
PC											

Ausbrooks, S. M. and S. Horton, 2013 Disposal of Hydrofracking-Waste Fluid by Injection into Subsurface Aquifers Triggers Earthquake Swarm in Central Arkansas with Potential for Damage Earthquakes: Ground Water Protection Council 2013 Proceedings, Day 2, [http://www.gwpc.org/sites/default/files/event-sessions/Ausbrooks\\_Scott.pdf](http://www.gwpc.org/sites/default/files/event-sessions/Ausbrooks_Scott.pdf)

FIGURE F- 5: CENTRAL ARKANSAS HISTORIC AREA SEISMICITY IN FOCUS AREA THROUGH 9/30/2013

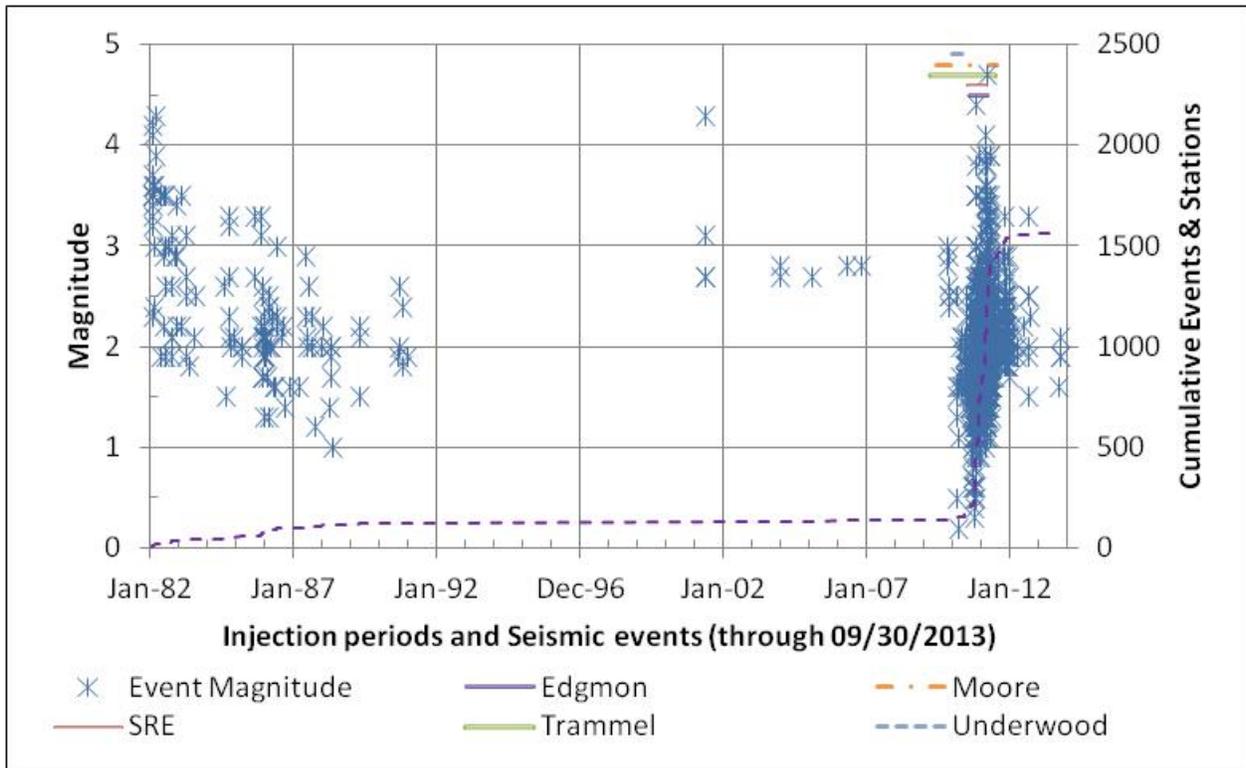


FIGURE F- 6: COMPOSITE FOCUS AREA SEISMICITY MAP

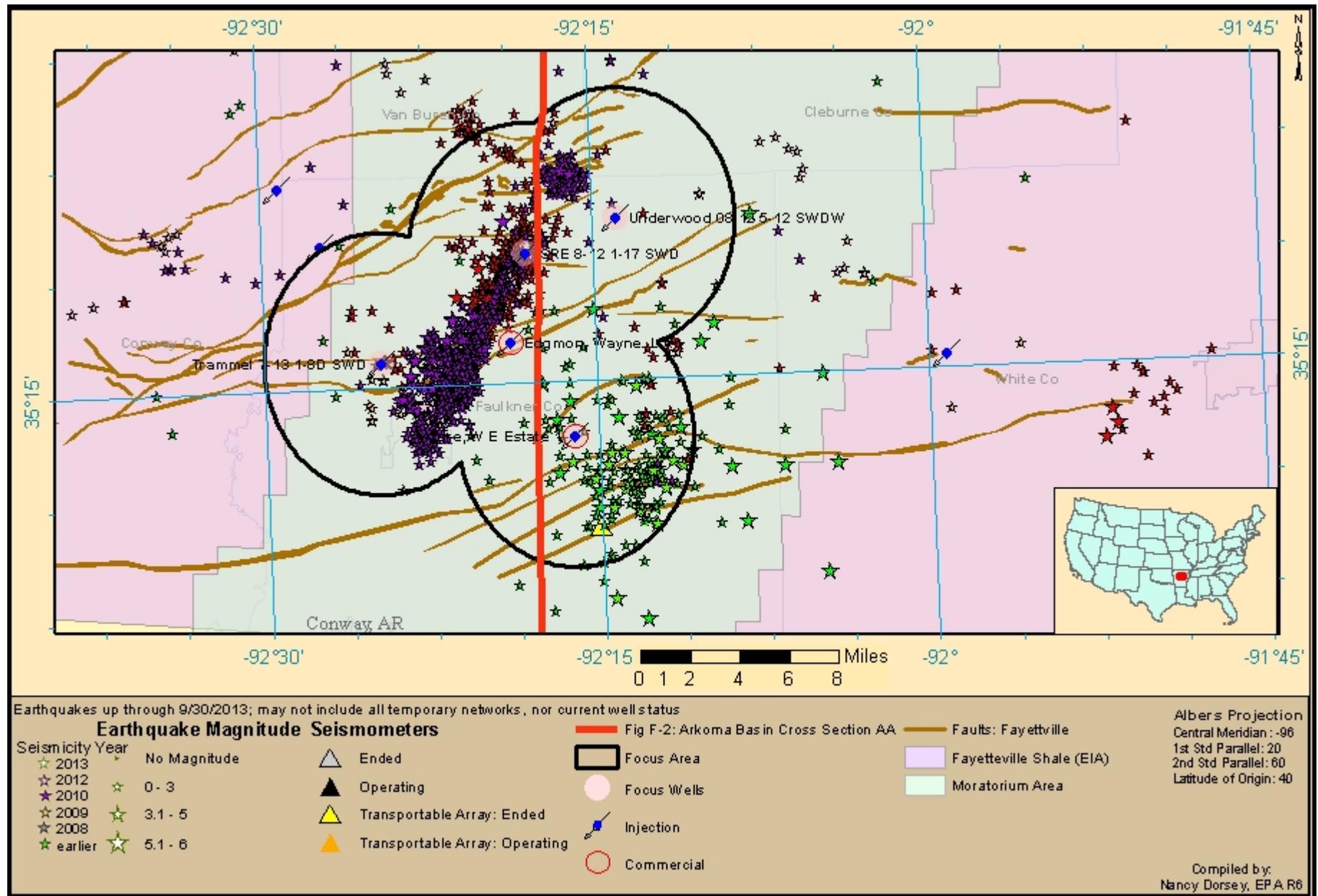
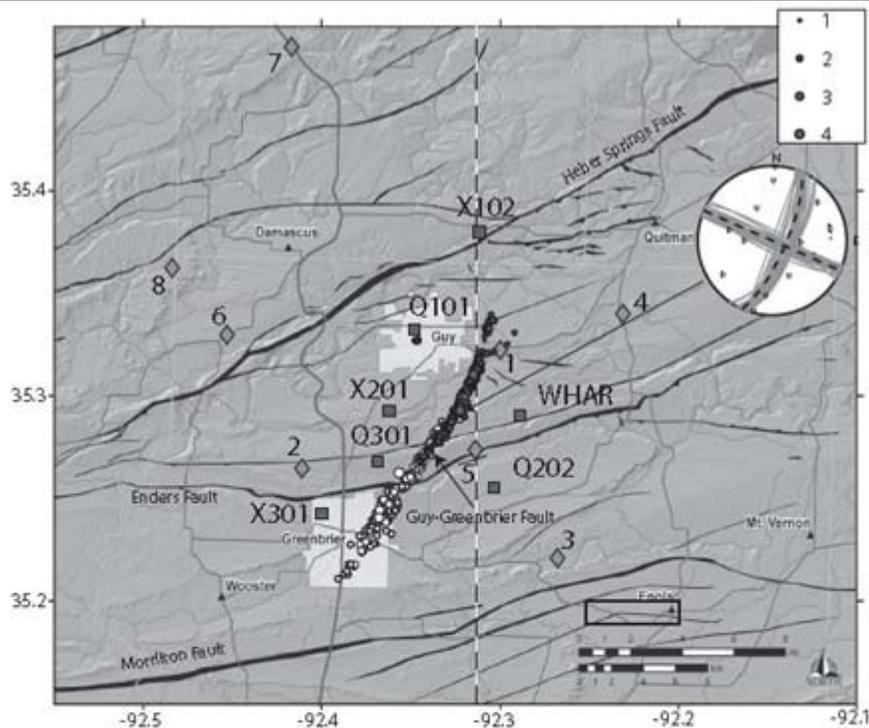


FIGURE F- 7: SEISMOMETER DEPLOYMENT AND ACTIVE FAULT TRACE (HORTON, 2012)



▲ **Figure 2.** Seismic stations (black squares), UIC wells (gray diamonds, Table 1), earthquakes (dark gray filled circles) between 1 October 2010 and 15 February 2011, and earthquakes (white filled circles) between 02/16/11 and 03/08/11. Named faults penetrate to the Precambrian basement (faults from AGS and AOGC). Earthquakes were located using HypoEllipse (Lahr 1999) and the velocity model of Chiu *et al.* (1994), then relocated using hypoDD (Waldhauser 2001) with the same velocity model. Inset: First-motion focal mechanism for **M** 4.0 earthquake on 11 October 2010 is consistent with right-lateral strike-slip on a NE oriented fault. North/south dashed line coincides with the geologic cross-section in Figure 4.

Horton, S. P., 2012, Disposal of Hydrofracking-waste fluid by injection into subsurface aquifers triggers earthquake swarm in Central Arkansas with potential for damaging earthquakes: *Seismological Research Letters*, v. 83, p. 250-260, doi: 10.1785/gssrl.83.2.250.

Wells 1 = SRE 8-12 1-17; 2 = Trammel 7-13 1-8D; 3=Moore 1-22; 4=Underwood 8-12 5-12; 5 = Edgmon 1

FIGURE F- 8: CENTRAL ARKANSAS COMPOSITE FOCUS AREA SEISMICITY

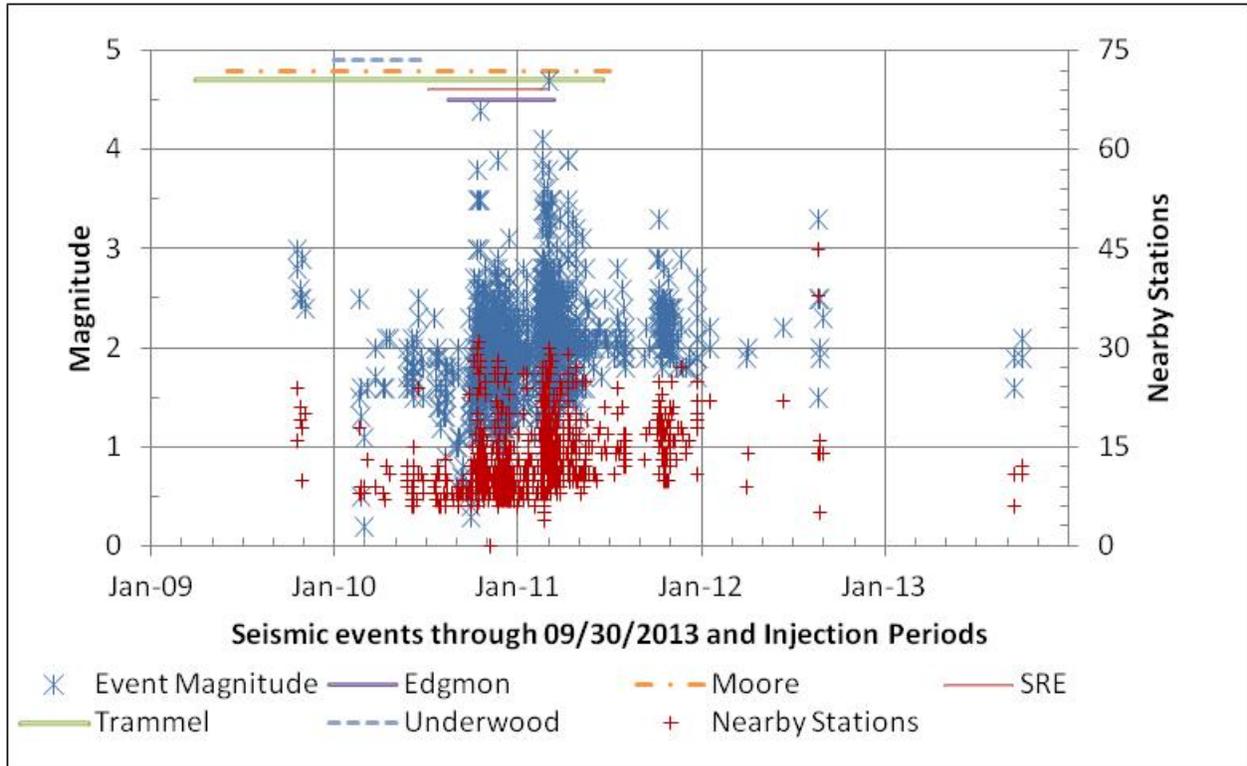


FIGURE F- 9: MOORE ESTATE OPERATIONAL DATA PLOT

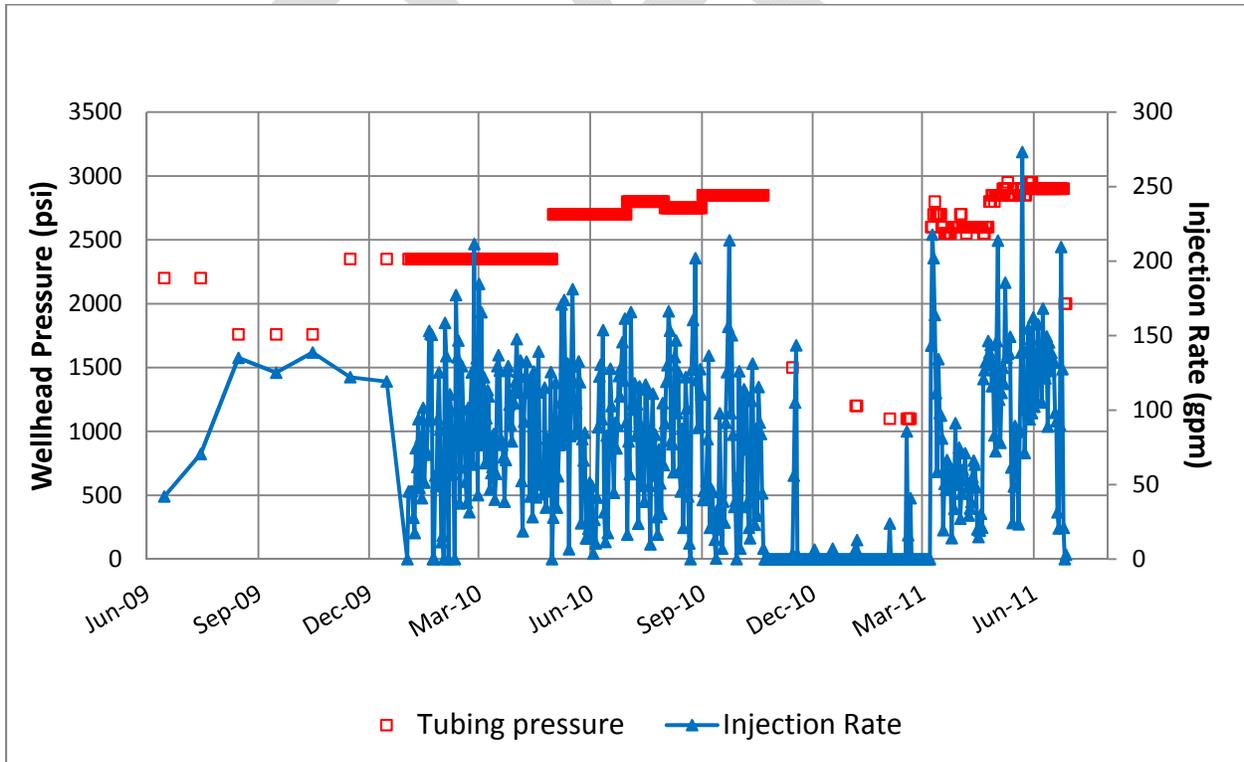


FIGURE F- 10: SRE OPERATING DATA PLOT

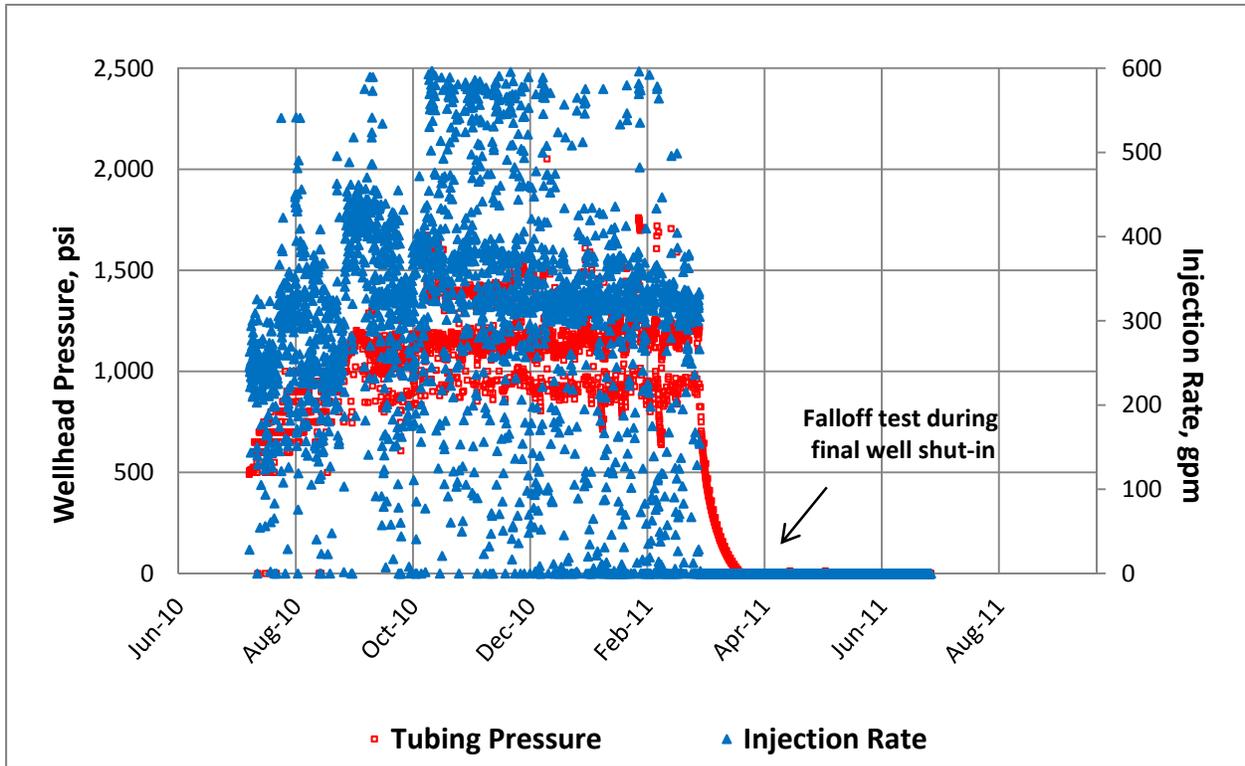


FIGURE F- 11: TRAMMEL OPERATING DATA PLOT

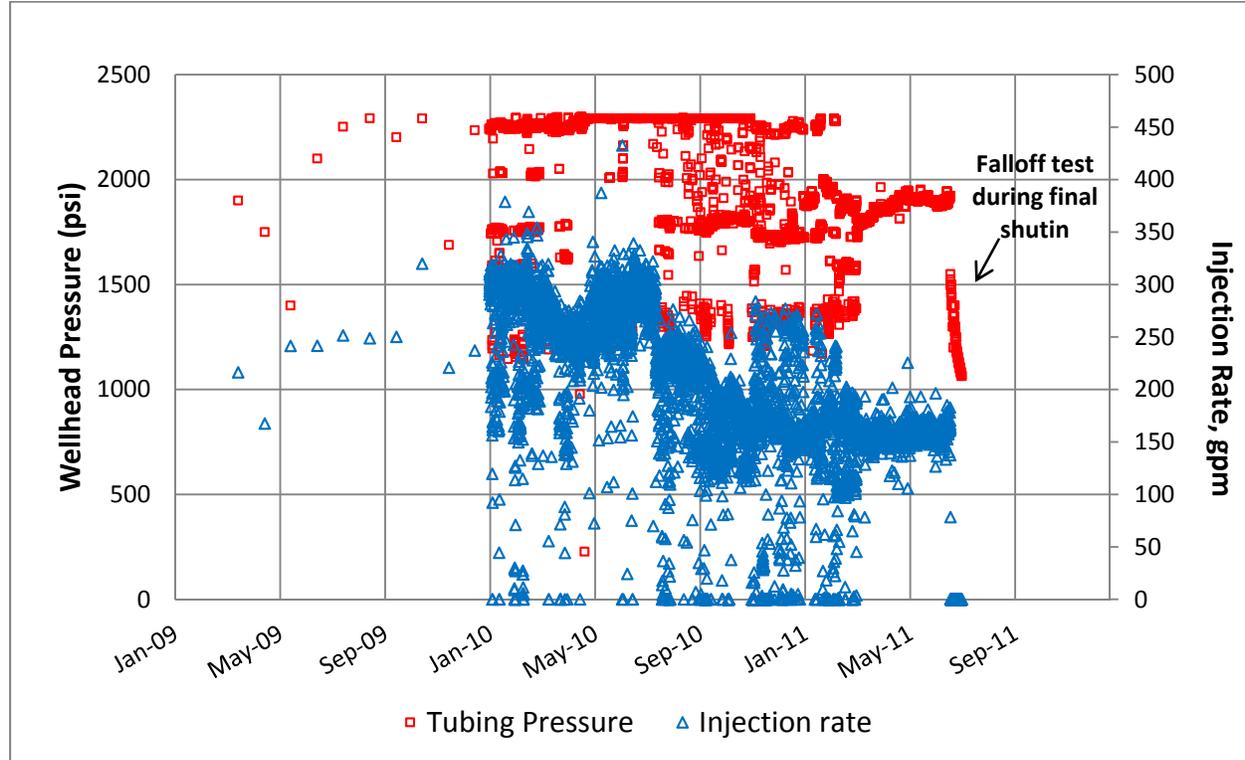


FIGURE F- 12: UNDERWOOD OPERATING DATA PLOT

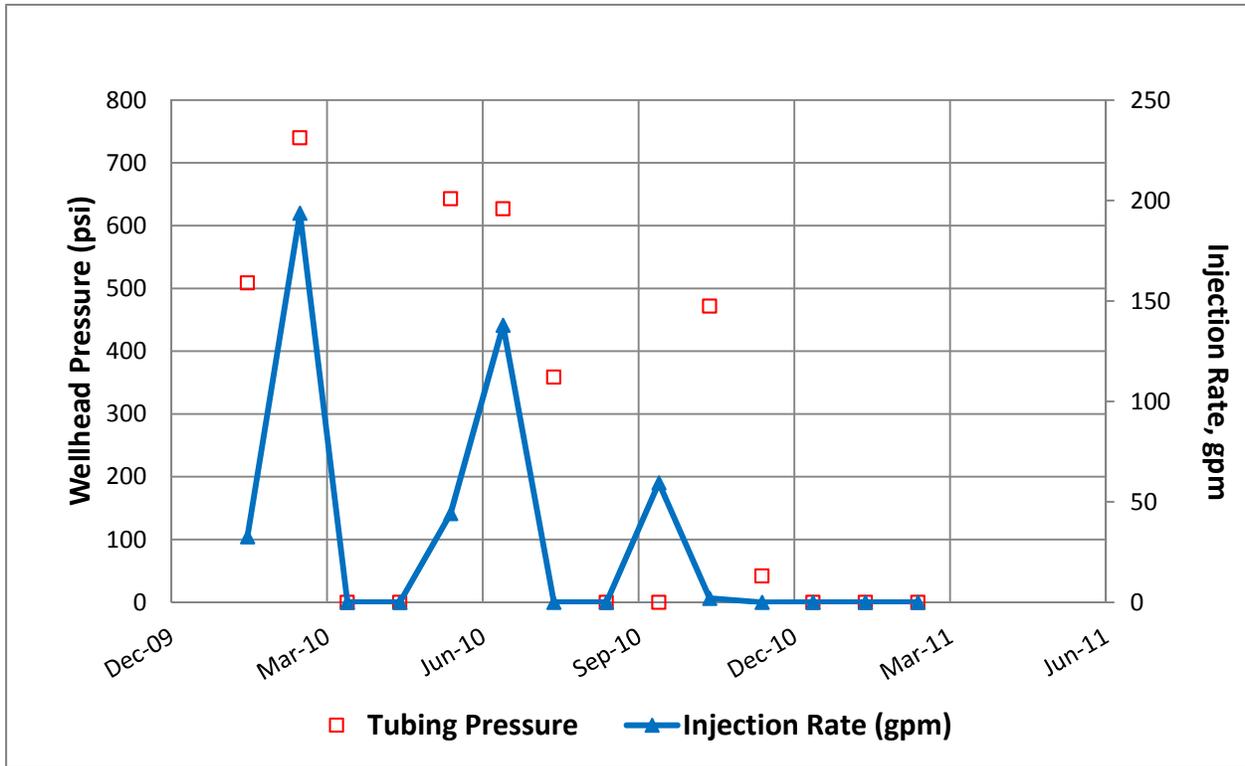


FIGURE F- 13: EDGMON OPERATING DATA PLOT

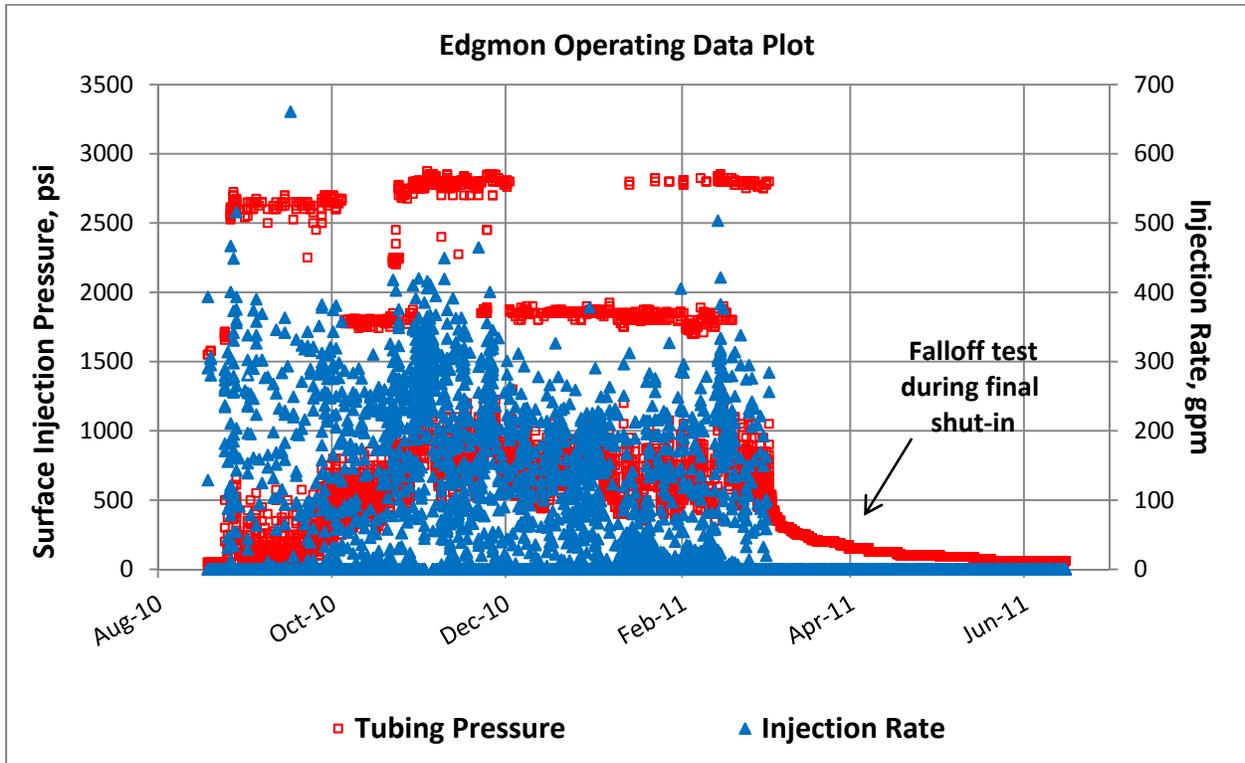


FIGURE F- 14: MOORE ESTATE OPERATING PRESSURE GRADIENT PLOT

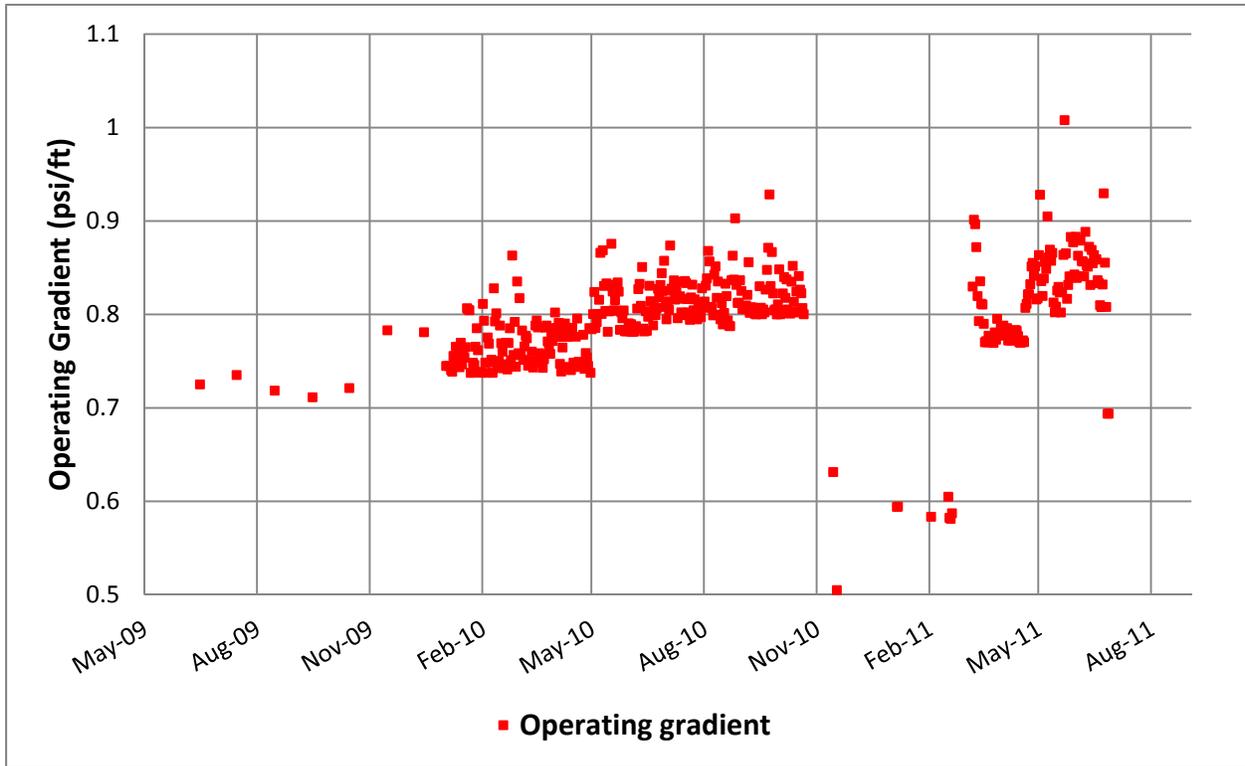


FIGURE F- 15: SRE OPERATING PRESSURE GRADIENT PLOT

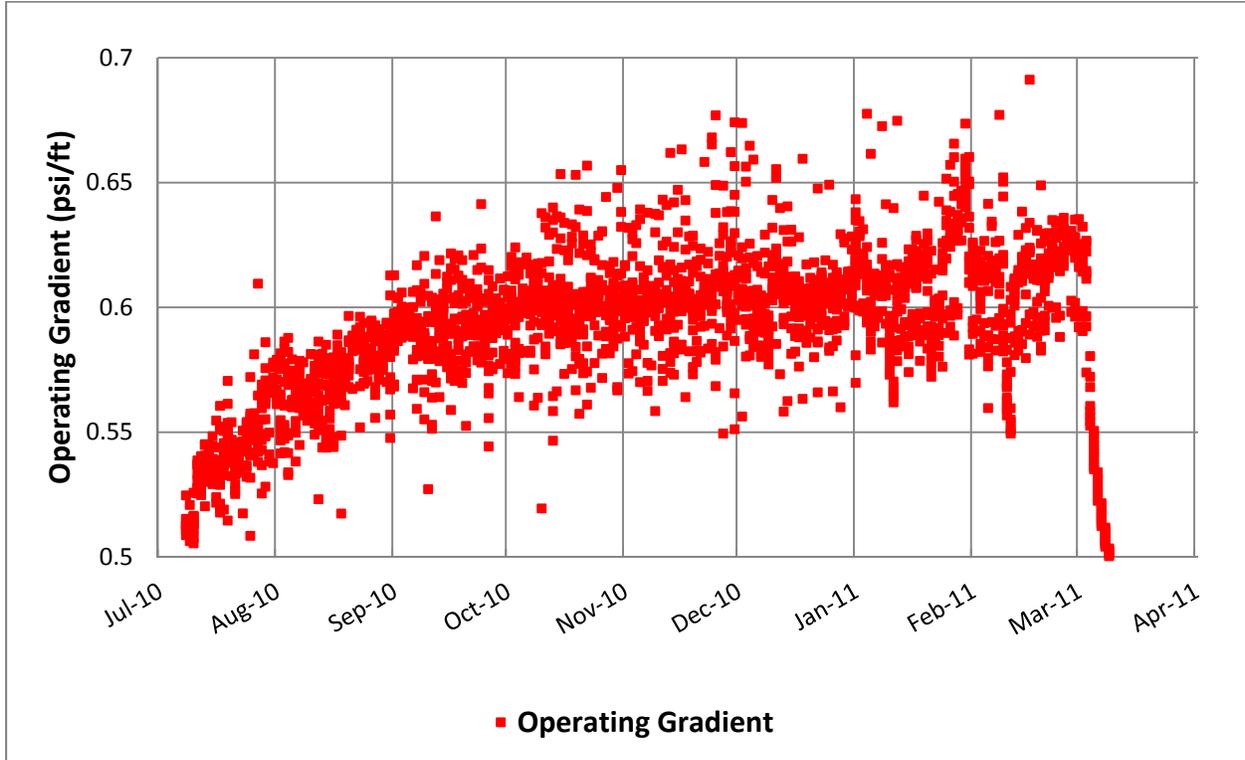


FIGURE F- 16: TRAMMEL OPERATING PRESSURE GRADIENT PLOT

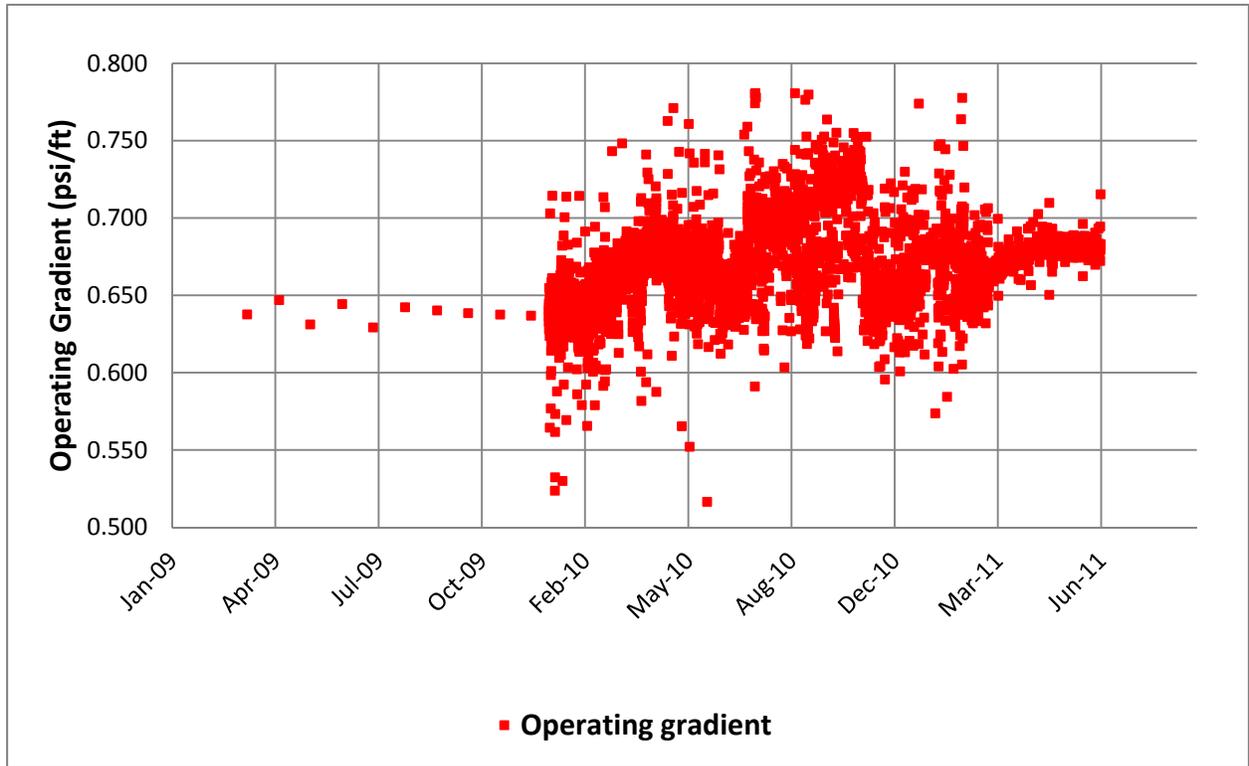


FIGURE F- 17: UNDERWOOD OPERATING PRESSURE GRADIENT PLOT

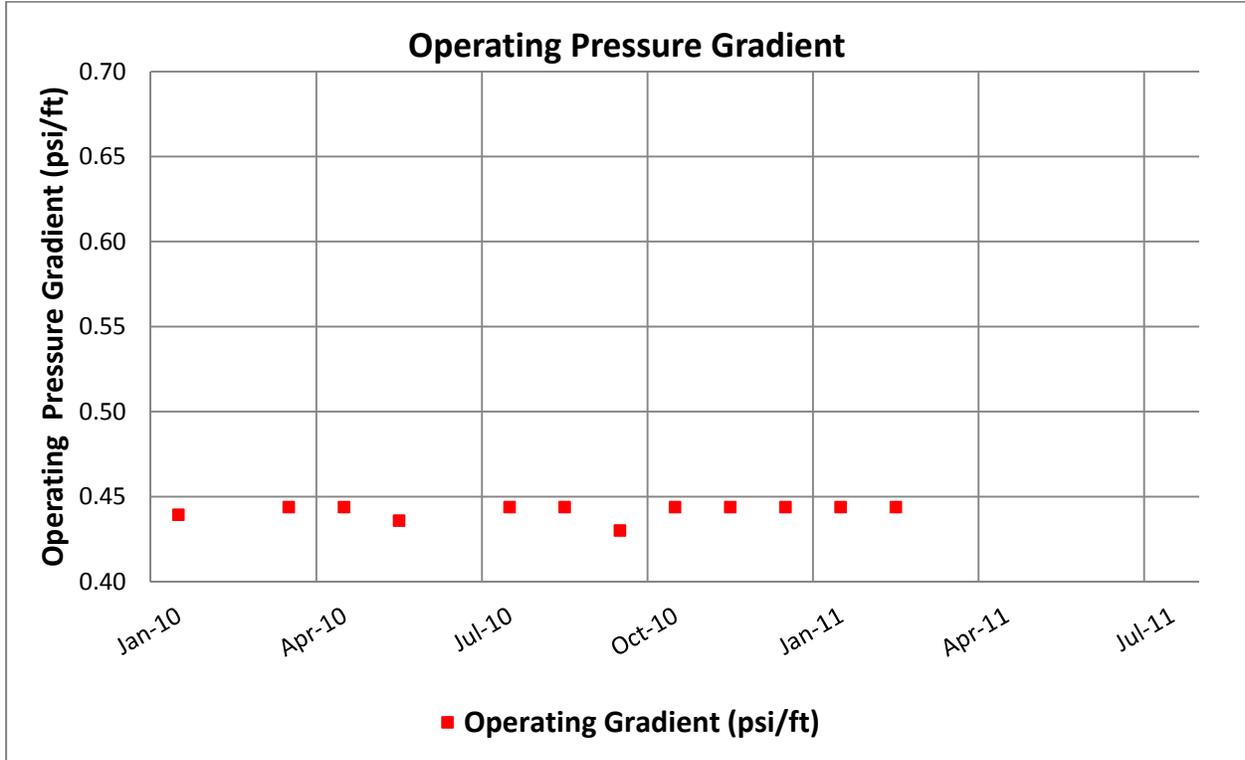


FIGURE F- 18: EDGMON OPERATING PRESSURE GRADIENT PLOT

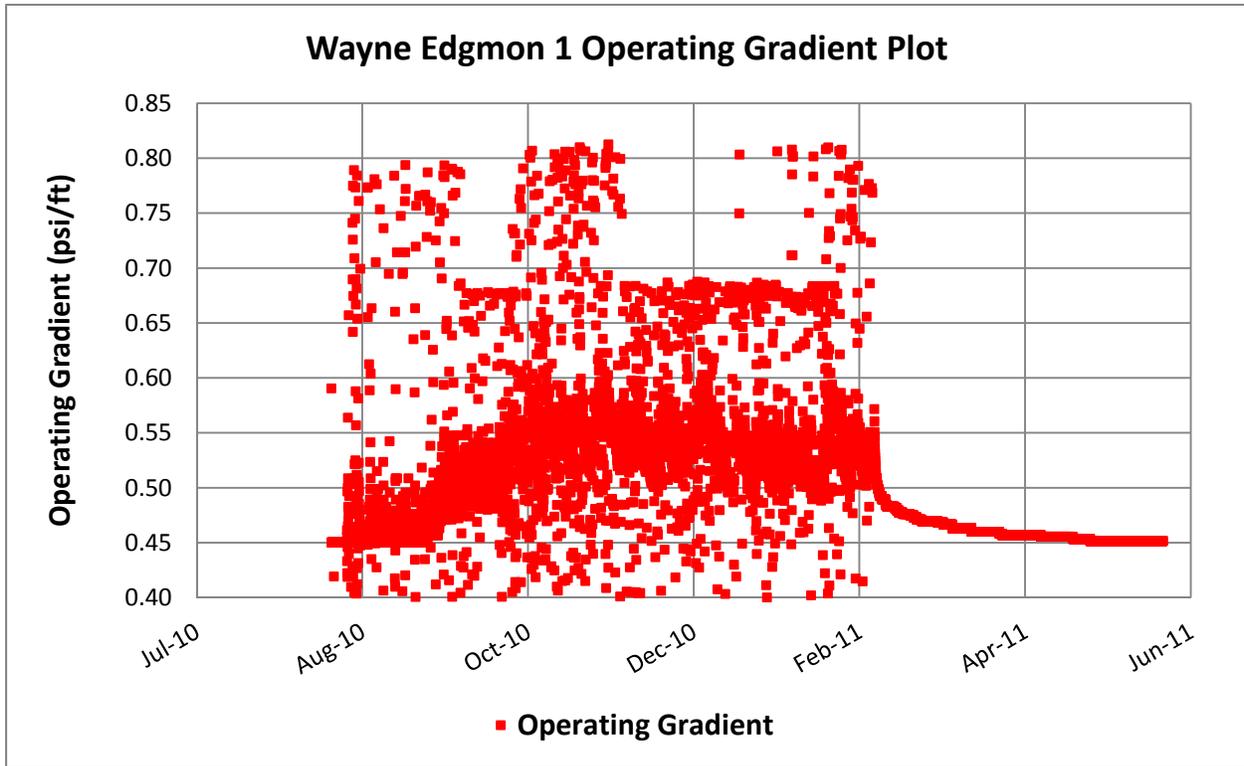


FIGURE F- 19: MOORE ESTATE TANDEM PLOT OF CUMULATIVE EARTHQUAKE EVENTS AND HALL INTEGRAL WITH DERIVATIVE

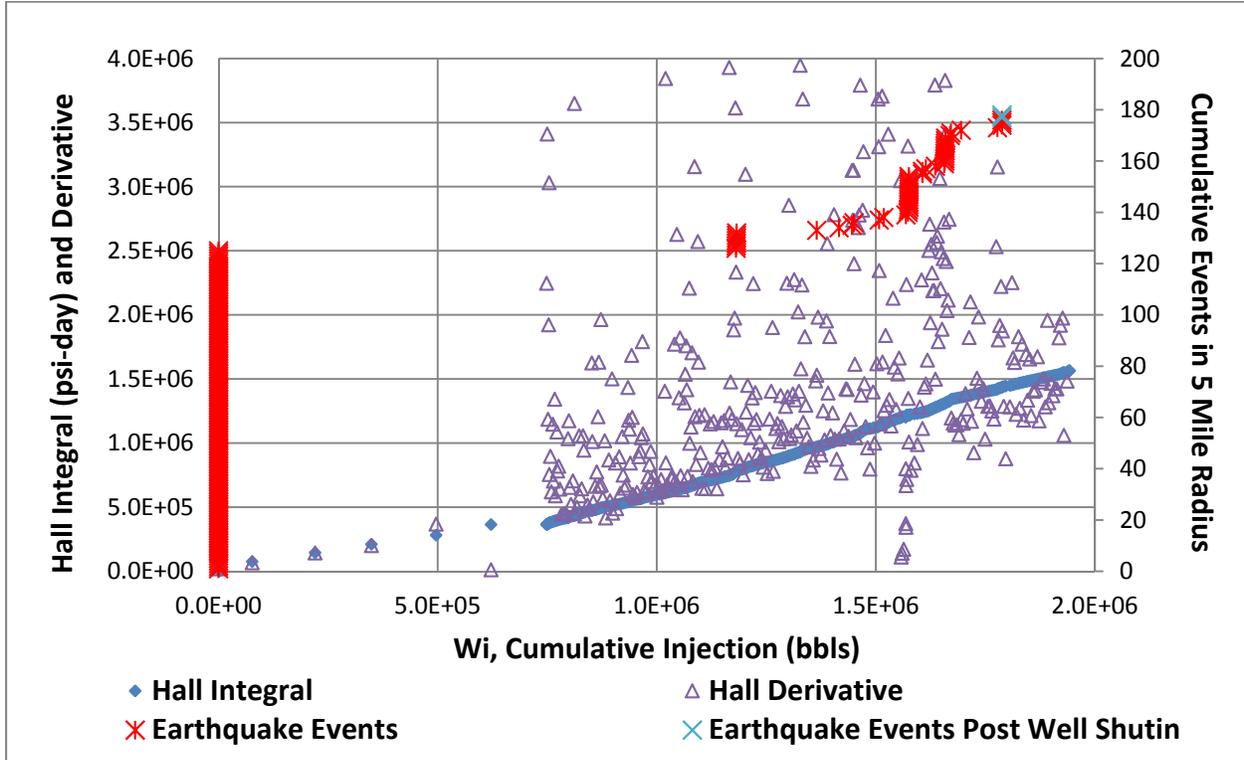


FIGURE F- 20: MOORE ESTATE TANDEM PLOT OF CUMULATIVE EARTHQUAKES SINCE 2010 AND HALL INTEGRAL

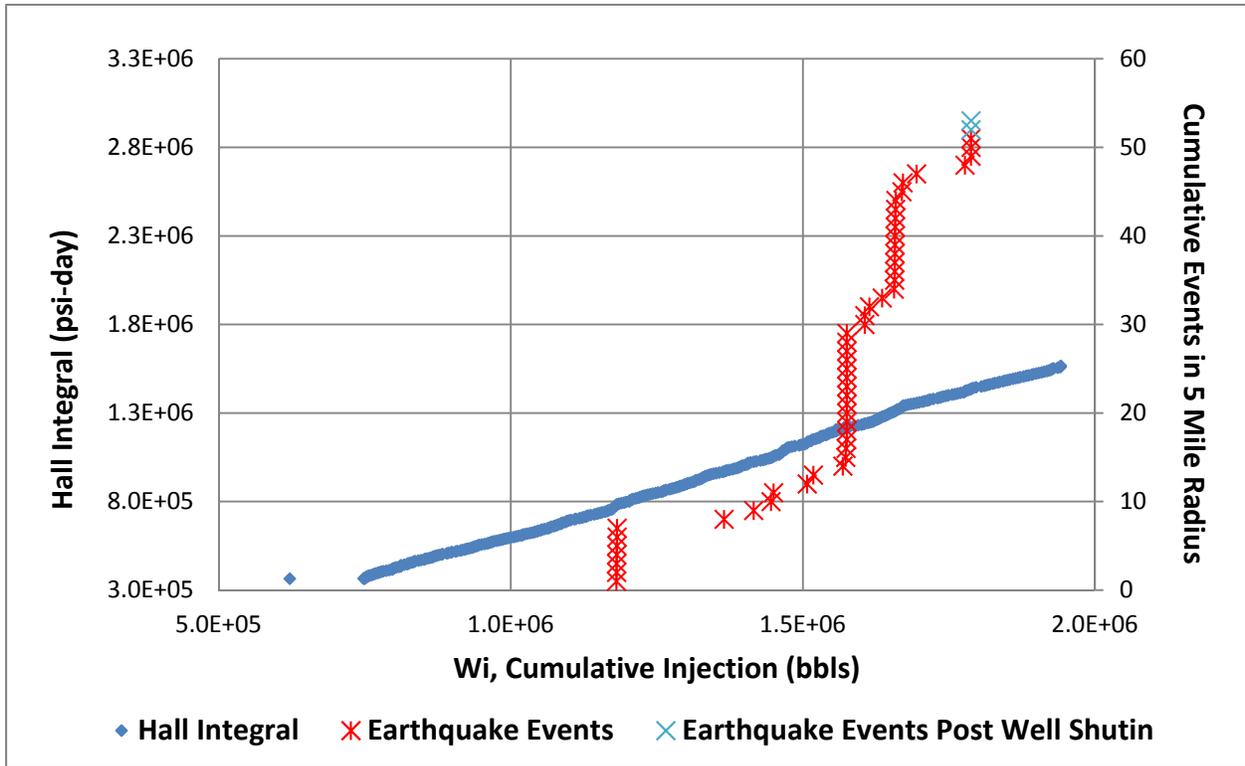


FIGURE F- 21: MOORE ESTATE ZOOMED TANDEM PLOT

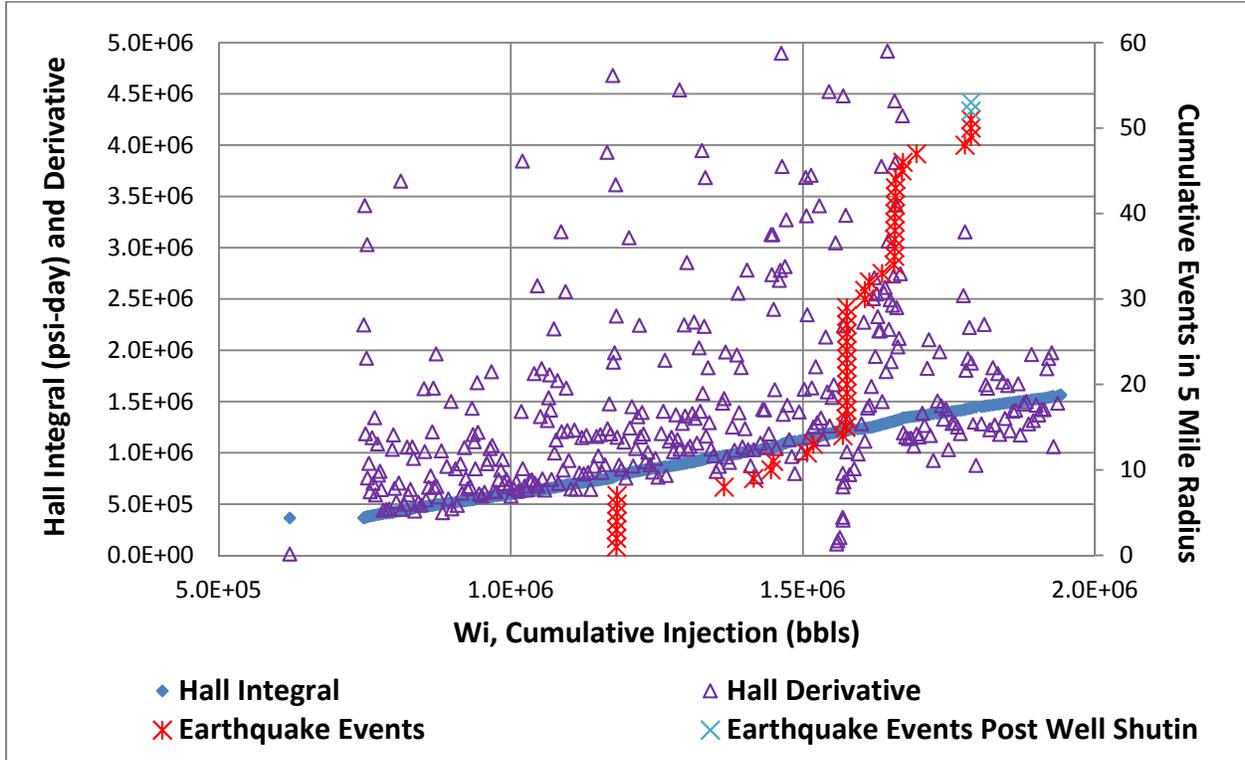


FIGURE F- 22: SRE TANDEM PLOT OF CUMULATIVE EARTHQUAKES AND HALL INTEGRAL WITH DERIVATIVE

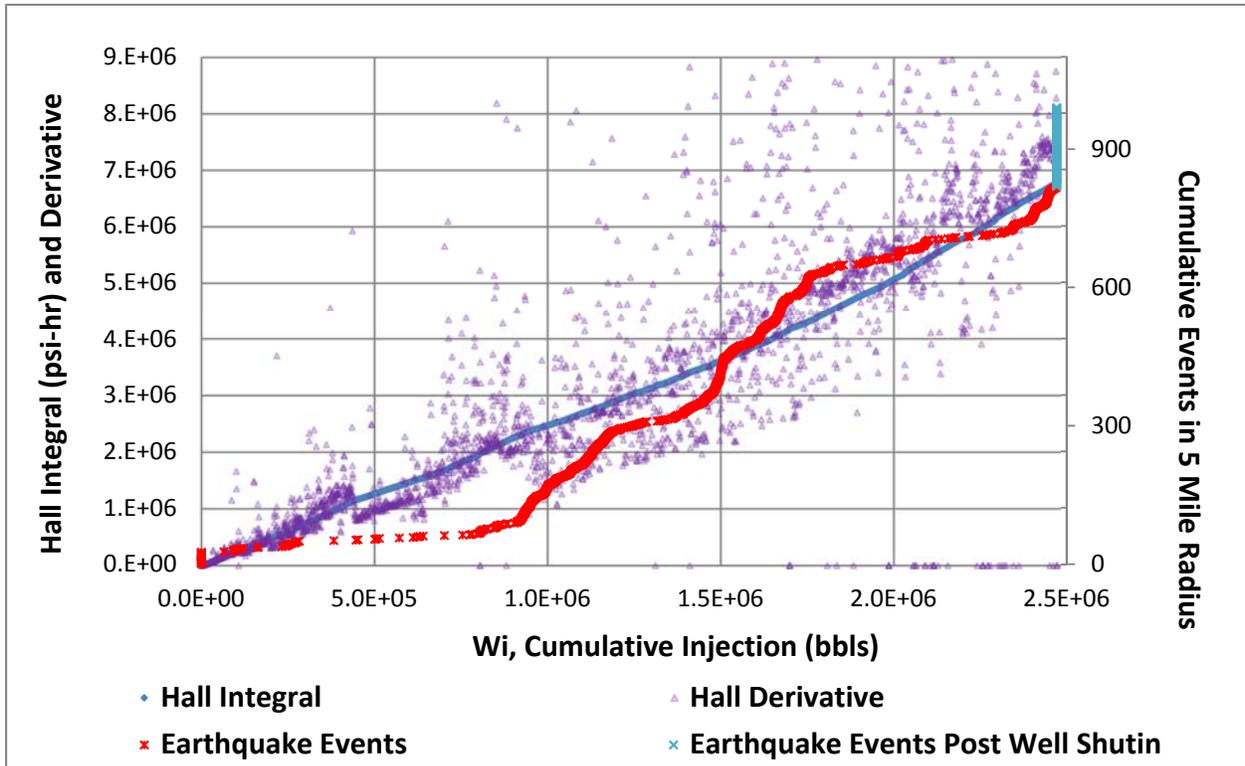


FIGURE F- 23: SRE ZOOMED TANDEM PLOT TO NOVEMBER 21, 2010

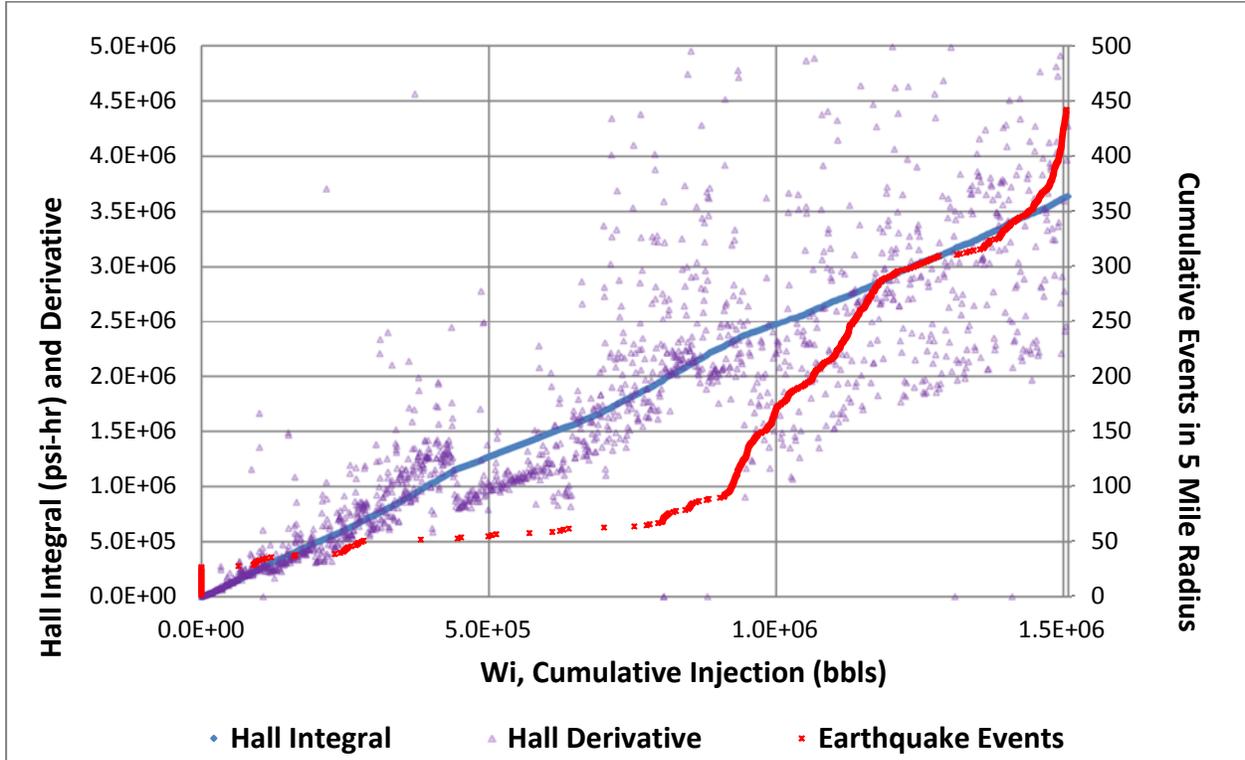


FIGURE F- 24: TRAMMEL TANDEM PLOT OF CUMULATIVE EARTHQUAKE EVENTS AND HALL INTEGRAL WITH DERIVATIVE

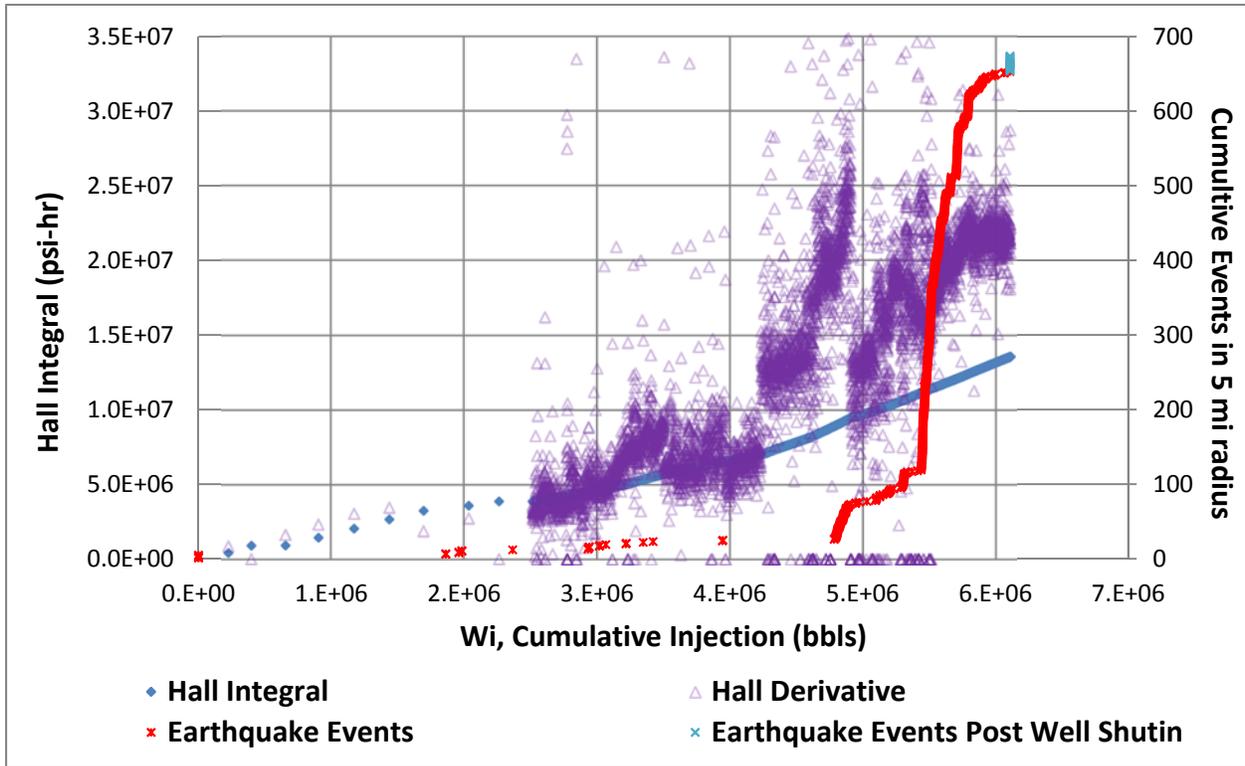


FIGURE F- 25: TRAMMEL TANDEM PLOT OF CUMULATIVE EARTHQUAKES AND HALL INTEGRAL

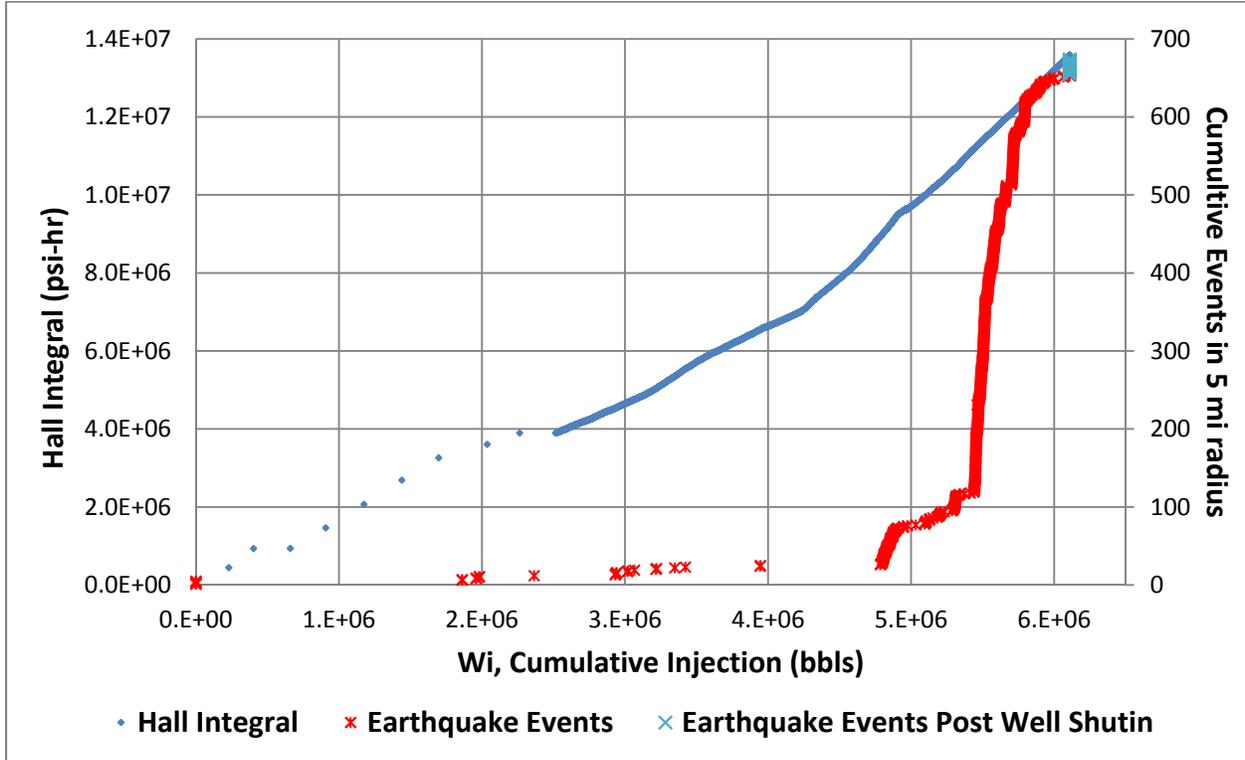


FIGURE F- 26: EDGMON TANDEM PLOT OF CUMULATIVE EARTHQUAKES AND HALL INTEGRAL WITH DERIVATIVE

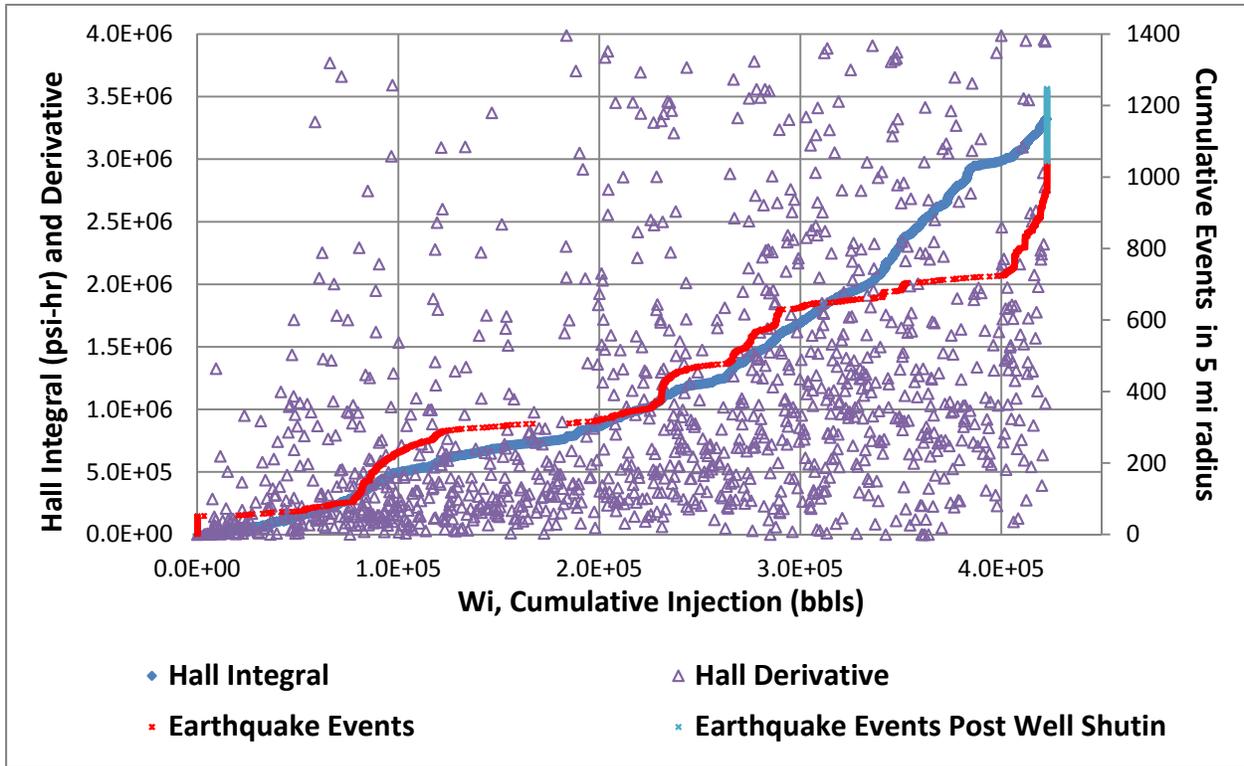


FIGURE F- 27: EDGMON TANDEM PLOT OF CUMULATIVE EARTHQUAKE EVENTS AND HALL INTEGRAL

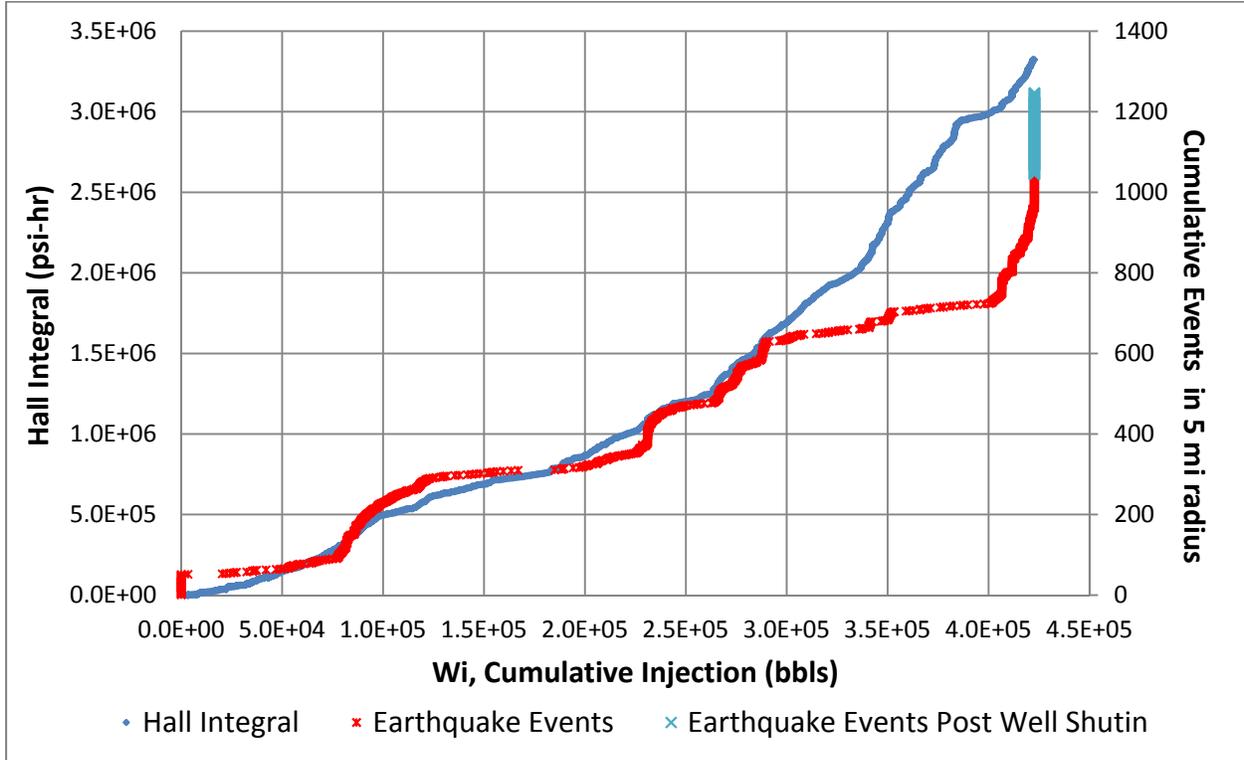


FIGURE F- 28: EDGMON ZOOMED TANDEM PLOT OF EARLY DATA TO DECEMBER 19, 2010

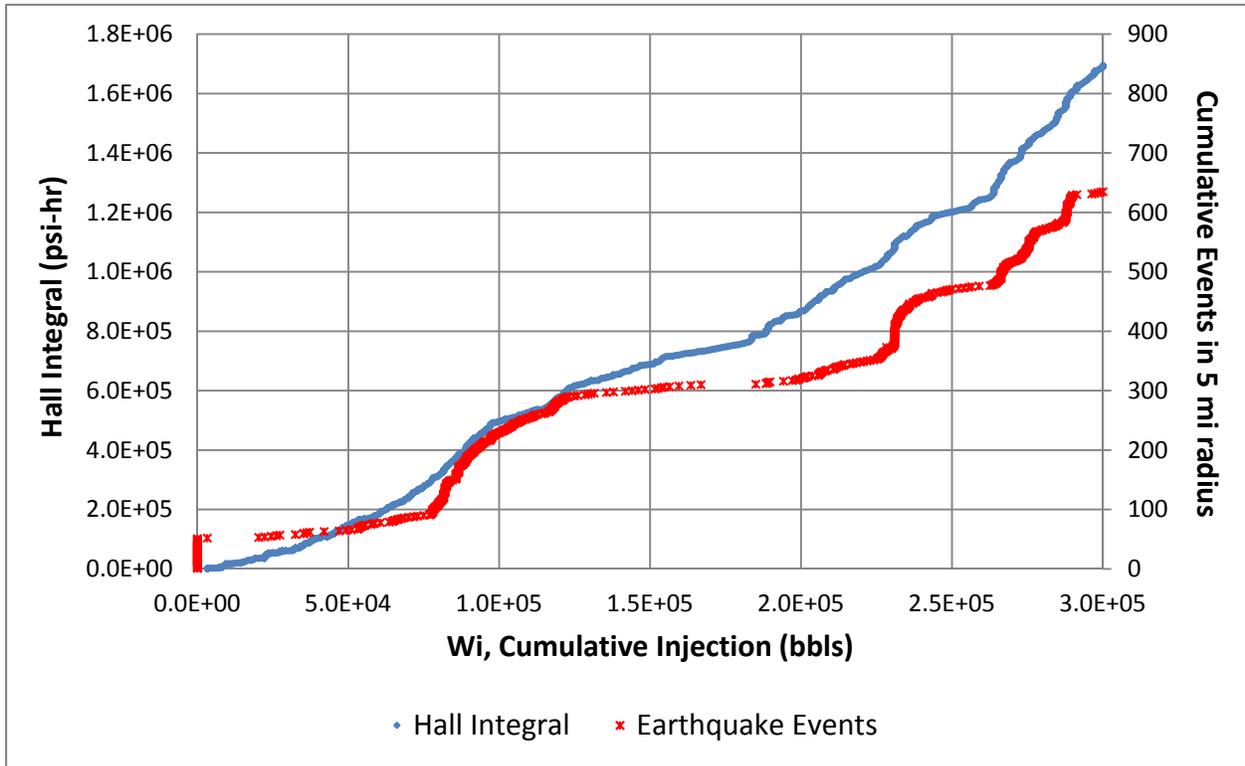


FIGURE F- 29: EDGMON STEP RATE TEST

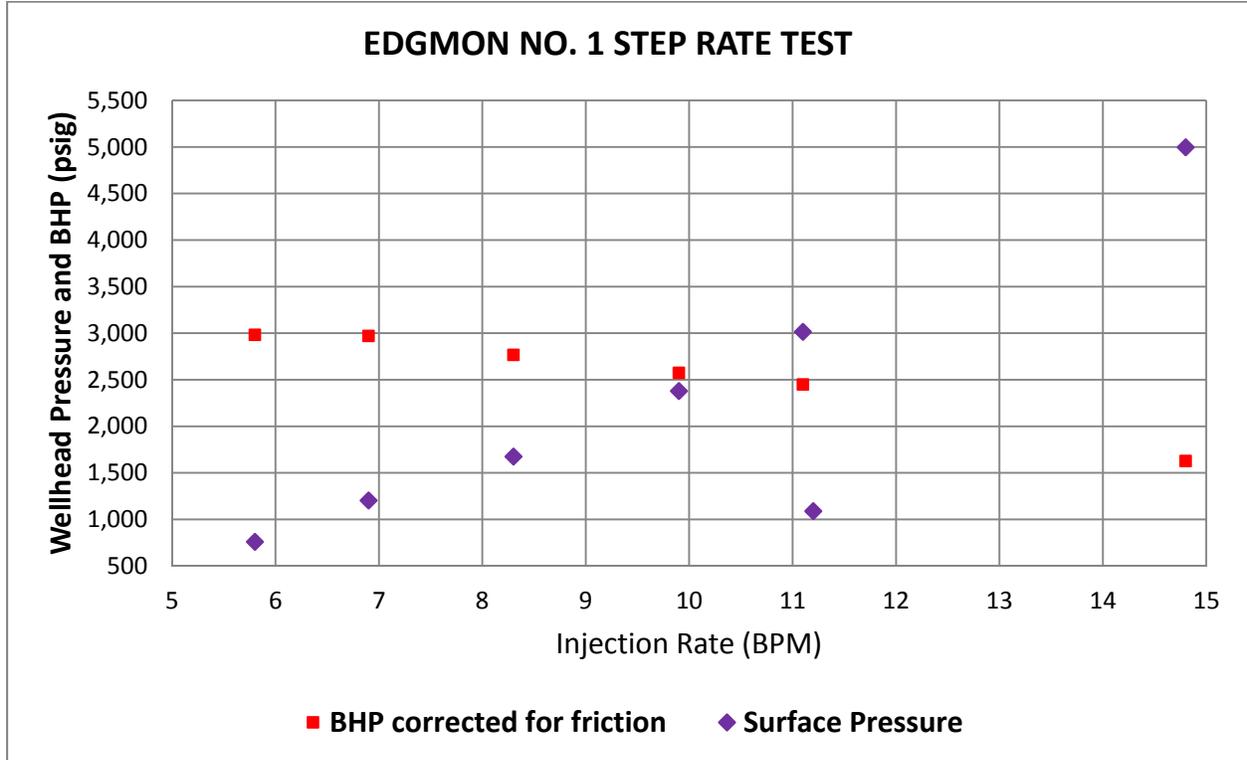


FIGURE F- 30: SRE LOG-LOG PLOT OF PRESSURE FALLOFF DURING FINAL SHUT-IN OF WELL

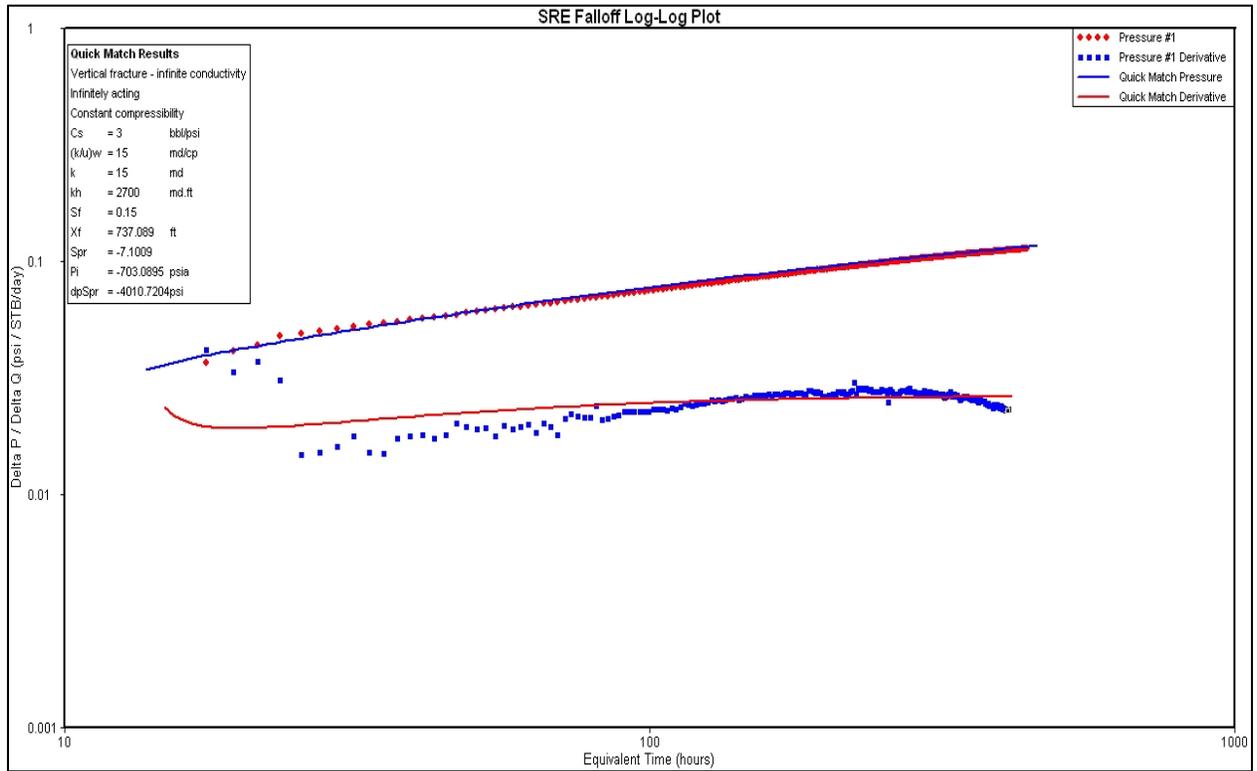


FIGURE F- 31: TRAMMEL LOG-LOG PLOT OF PRESSURE FALLOFF DURING FINAL SHUT-IN OF WELL

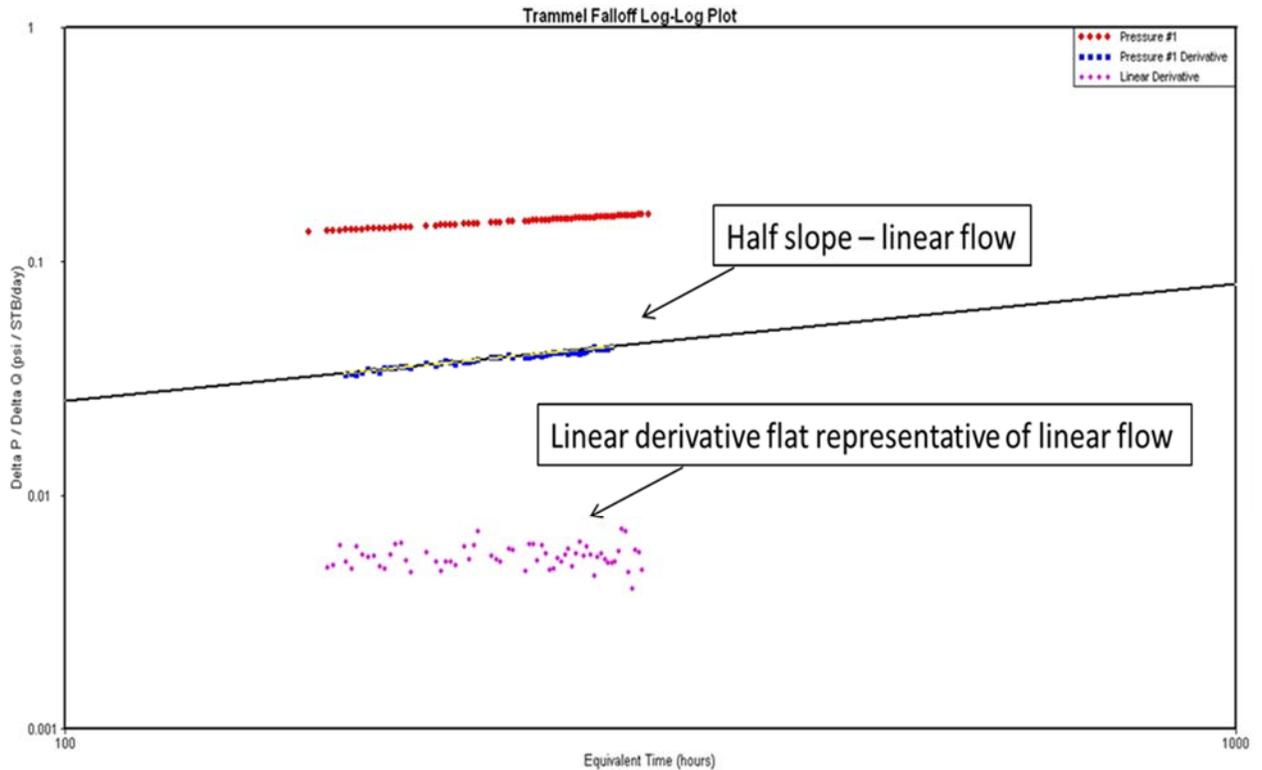


FIGURE F- 32: EDGMON LOG-LOG PLOT OF PRESSURE FALLOFF DURING FINAL SHUT-IN OF WELL

